

Epidemiology of Helicopter Battle Damage

Mr. Kevin Rotenberger and Mr. Kevin Rees

Aviation Engineering Directorate (AED) Corpus Christi
308 Crecy Street, Mail Stop 55
Corpus Christi, TX 78419
USA

krees@us.army.mil

1.0 INTRODUCTION

The US Army has over 400 aircraft deployed in support of Operations Iraqi Freedom and Enduring Freedom (OIF/OEF). That includes an array of fixed and rotary wing aircraft that spans the mission areas of attack, reconnaissance, utility, MEDEVAC, intelligence gathering, cargo and troop transport. This fleet of aircraft is employed and maintained in the fight through a combination of unit rotations with equipment and a select Stay Behind Equipment (SBE) with new units rolling in on existing equipment. The lifecycle maintenance and repair of aircraft includes all echelons of maintenance operations including unit level, intermediate, RESET operation back at home station and depot. This lecture series explores the maintenance practices, procedures organization structures and special maintenance programs that have evolved to maintain a large aviation fleet in combat overseas and effectively deal with battle damaged aircraft. The presentations will also look at the equipment and TTP's that have been employed to mitigate causal factors contributing to aircraft damage.

2.0 US ARMY ACCIDENT & DAMAGE STATISTICS

The US Army tracks aircraft accident incident information at the US Army Combat Readiness Center. Accidents and incidents are classified into four categories as a ranked function of either damage to the aircraft in dollars to fix and repair or by injury to the crew. The classification definition of incidents is shown in Table 1 below. For the purposes of this study, we will examine Class A through Class C accident data, and consider the data to be representative of the spectrum of damage that must be dealt with by deployed maintenance units. An analysis of the data by year dating back to 1995 was done to look at the effect of OIF and OEF on overall aircraft incident rate. This rate is used as an indicator of aircraft battle damage and the impact on US Army operations. Chart 1 shows the summation of Class A through Class C accidents for all years from 1995-2009. The graph clearly indicates the effects of OIF and OEF in the increased incident occurrences beginning in 2002 with the onset of OEF as compared to the period of peacetime immediately prior. The same plot of strictly Class A incidents is shown in Chart 2 with pronounced effect identified in the time periods coinciding with the beginning of operations OIF and OEF. However, to incorporate the effects of OPTEMPO increases, Charts 3 and 4 look at the incident rates per 100,000 flight hours for Class A and Class A through Class C respectively. The effect of current operations is much less pronounced but still indicates an approximate 2 times increase in incident rates during OIF/OEF operations.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE MAY 2010		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Epidemiology of Helicopter Battle Damage				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Aviation Engineering Directorate (AED) Corpus Christi 308 Crecy Street, Mail Stop 55 Corpus Christi, TX 78419				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADA564486. Battle Damage Repair Techniques and Procedures on Air Vehicles - Lessons Learned and Prospects. RTO-EN-AVT-156, The original document contains color images.					
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15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 14	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

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Table 1: US Army Accident Classification

	Damage to Equipment	Human
Class A	Property Damage exceeding \$2M or Aircraft is Destroyed	Fatalities or Permanent Disabilities
Class B	Property Damage \$500K-\$2M	Injury resulting in permanent partial disability
Class C	Property Damage \$50K - \$500K	Injury causes 1 or more days away from work or training

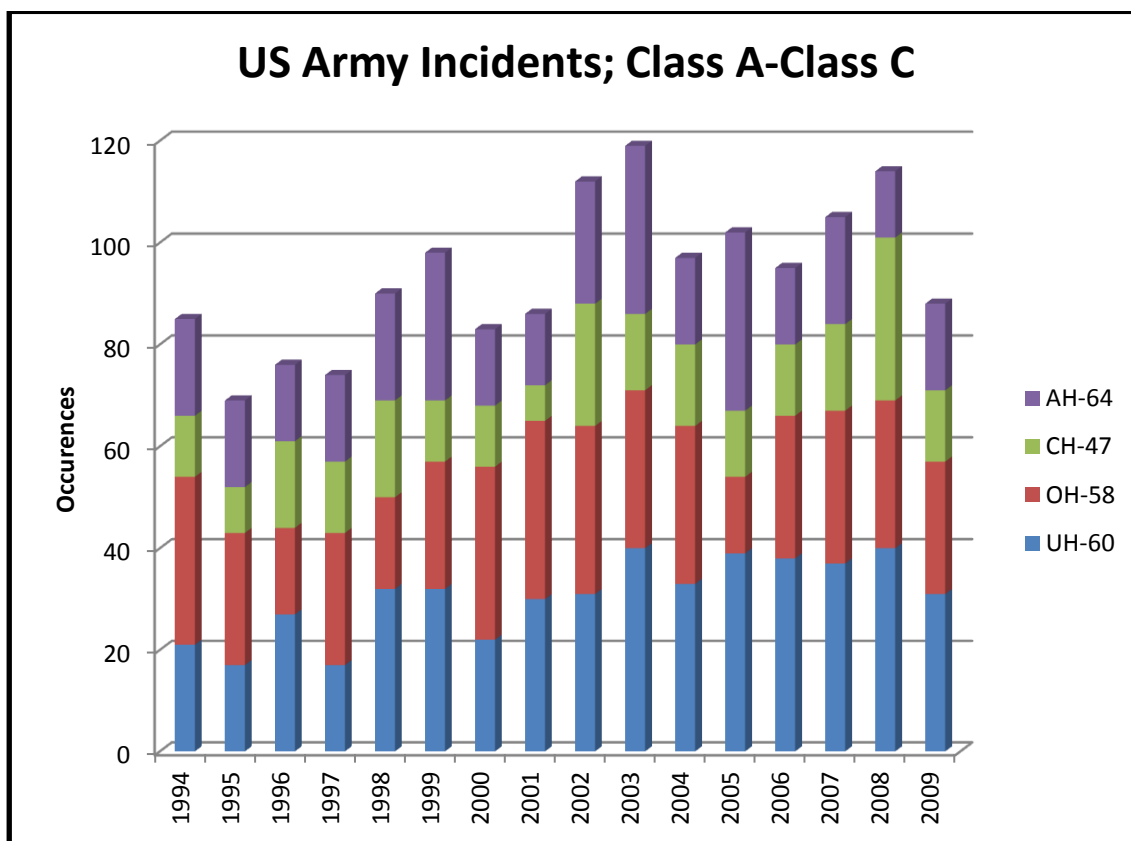


Figure 1: Summary of Class A-C Incidents for Four (4) Primary Aircraft, 1994-2009

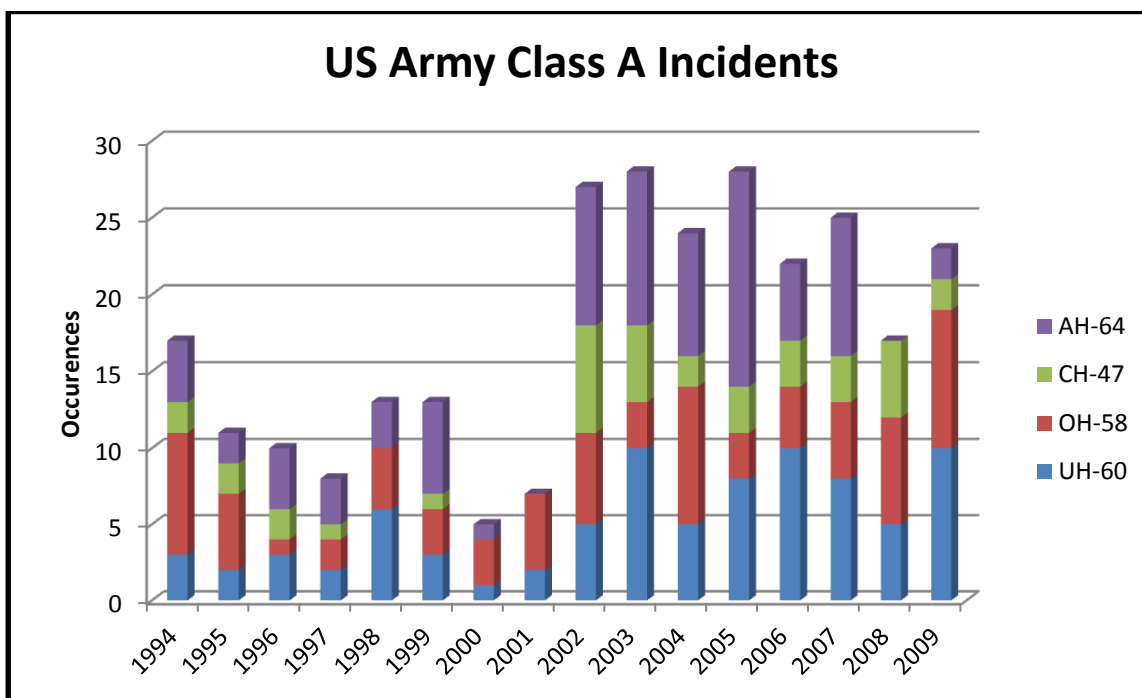


Figure 2: Class A Incidents for Four (4) Primary Aircraft, 1994-2009

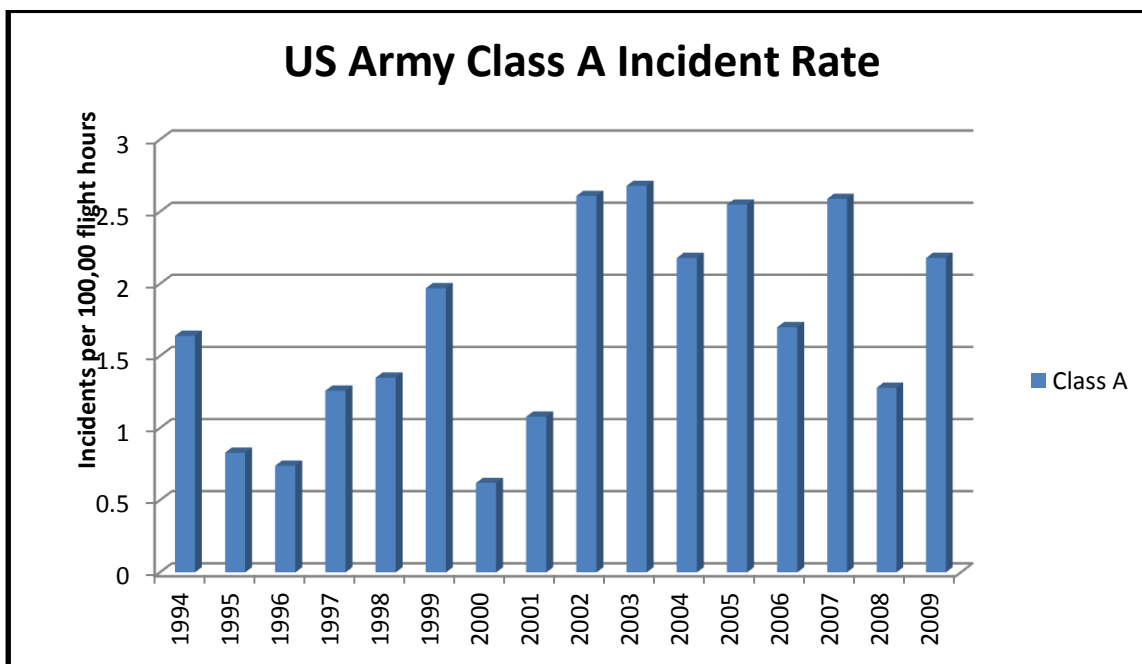


Figure 3: Class A Incident Rate for all Total Army Fixed and Rotary Wing

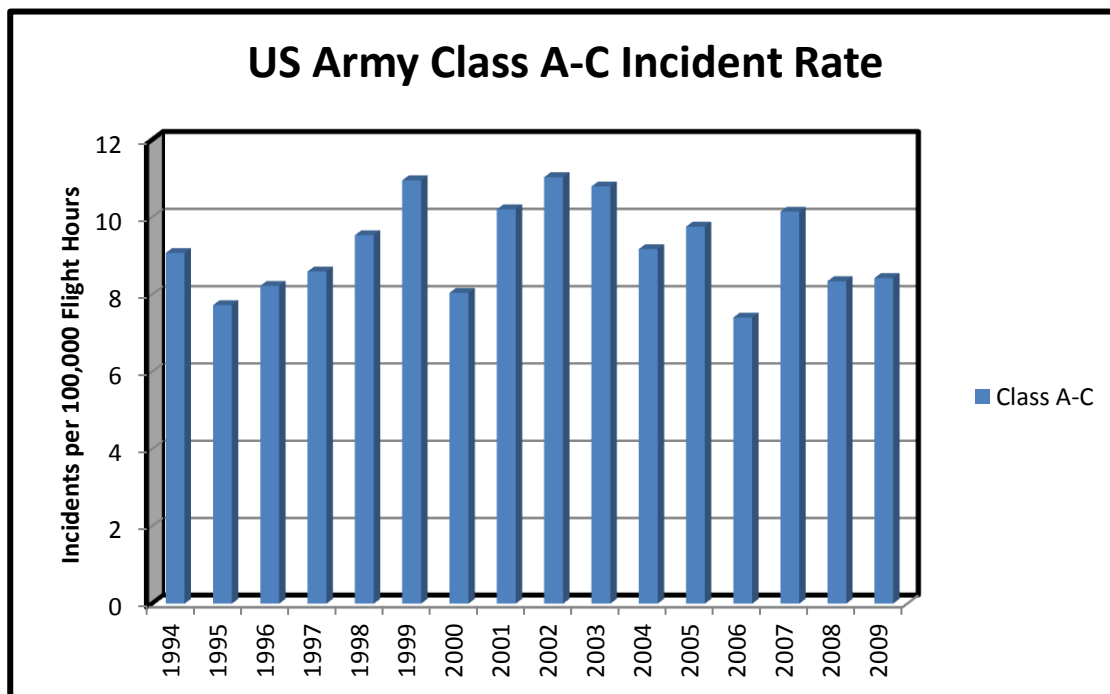


Figure 4: Class A-C Incident Rate for Total Army Fixed and Rotary Wing

3.0 CRASH DAMAGE REPAIR PROGRAM

Another measure of battle damage and the impact on Army Aviation fleet is the statistics for the aircraft Crash Damage Repair program at Corpus Christi Army Depot. Through the Crash Damage Repair program, aircraft are rebuilt from the fuselage up. As you can see from figure 5, the crash damage program has been rebuilding 10-15 aircraft per year over since the beginning of OEF as compared to 2-3 aircraft per year prior to 2003. This data is a partial picture of the overall damage repair picture as it does not reflect other sources of repair such as aircraft inducted into a model upgrade line at the manufacturer. For example, currently CH-47Ds are being upgraded to CH-47F's by Boeing Helicopters. Some severely damaged aircraft are returned and inducted directly into the Mod program and are not reflected in the CCAD data. This data also does not reflect aircraft that are destroyed in place due to security concerns in retrieving the aircraft. Those losses are not reflected in the CCAD crash damage repair data. There is no definitive single source of data that exists in the Army that integrates all sources of damage repair information across all elements of the Army.

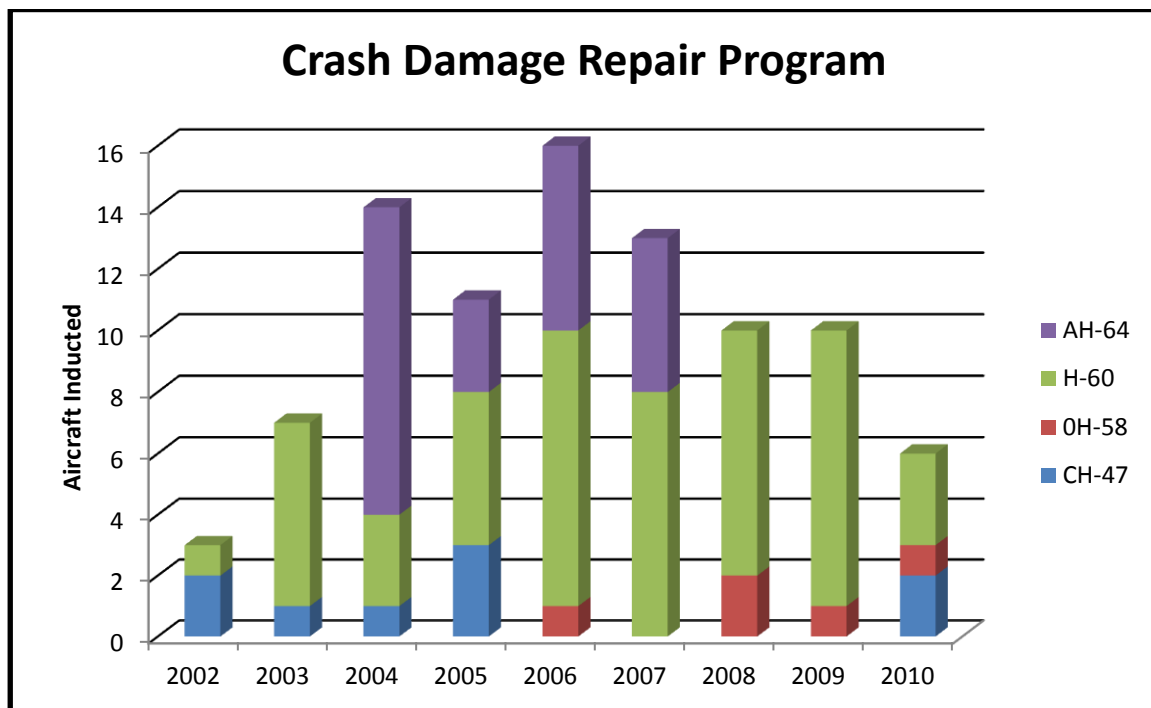


Figure 5: US Army Crash Damage Repair Program for the Four (4) Primary Aircraft, 2002-2010

4.0 CAUSAL FACTORS OF BATTLE DAMAGE

This paper now will categorize damage types and causal factors for aircraft battle damage and investigate the mitigating factors for each of the factors. This study does not intend to present an exhaustive study of the causal factors included in the aircraft incident numbers, but rather will present a qualitative assessment of the factors contributing to the accidents with a relative rank of importance. There are many causes of battle damage to aircraft and those causal factors are dynamic with time. Table 2 identifies 4 broad categories of causal factors contributing to battle damage to aircraft. It broadly identifies the relative severity of the factor as a function of time in the two current theatres of operation. The factors present and prevalent in the early days of Operation OIF in Iraq are not necessarily the current prevalent causal factors in Iraq. Each of the categories of causal factors will be briefly examined. The status and the technologies that have been employed to mitigate the casual factor will be explored.

5.0 WEAPONS EFFECTS

Damage due to weapons effects is the most obvious factor for damage to aircraft systems employed in combat. The types of weapons span the spectrum from small arms fire and unguided ballistics (RPG's) to guided missile systems. The potential aircraft damage due to weapons also includes aircraft damage in non flight operations such as the effects from direct or indirect attacks on airfield locations.

Frequency and Severity and Technologies: The type of weapons attack on aircraft and there resultant effectiveness varies by weapon type. Small arms attacks are a constant threat and little can be done in the technology arena to prevent such attacks. The only real mitigation of the event is within Tactics, Training and

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Procedures (TTP) employed in flight operations and the increased survivability designed and built into the aircraft to handle known threats. However, significant technology applications can be employed that can minimize the impact on the aircraft due to small arms fire. Most all aircraft have armor protection systems on the aircraft to protect the aircrew and critical aircraft systems. The most effective means of protecting the aircraft from small arms fire is to protect the crew and critical systems on the aircraft and allow the aircraft to safely operate the aircraft after the aircraft has sustained small arms fire. Effective armor systems provide maximum protection to the crew minimizing the occasions where minimal aircraft damage results in significant aircraft damage due to the inability of the crew to operate the aircraft.

Aircraft damage due to guided missile systems has a different dynamic. The aircraft damage due to missile strikes on aircraft are typically severe to catastrophic. The frequency of such events has changed dramatically over time in OIF/OEF and is directly attributable to the technologies employed to counter the threat. The technologies will not be discussed here but the impact in the field has been the significant reduction of missile shoot downs as a cause for aircraft damage or loss in OIF. The counter measures are effective today but must continue to evolve to meet the changing threat.

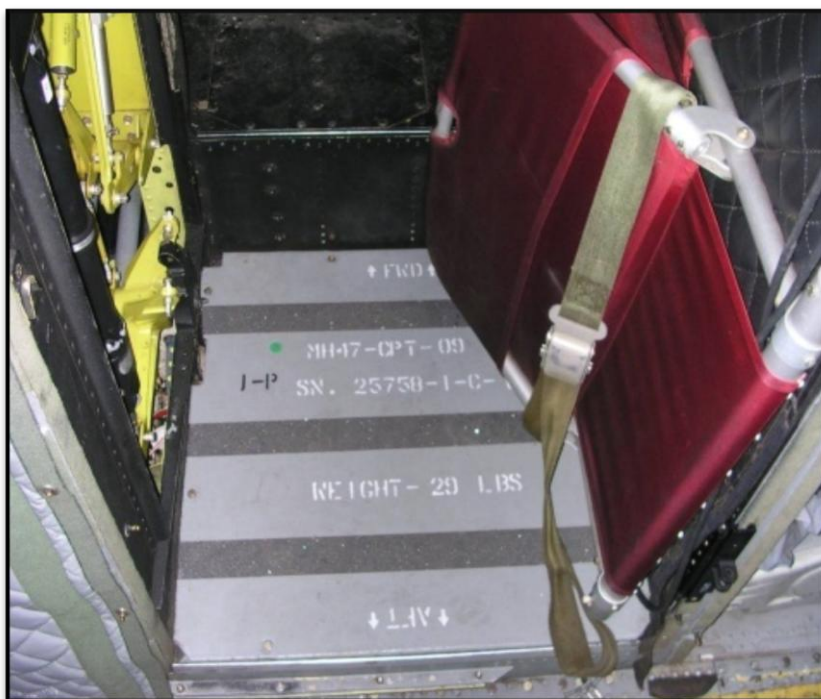


Figure 6: Ballistic Armor Protection System (BAPS)

6.0 ENVIRONMENTAL EFFECTS

The category of environmental effects includes heat, sand, dust, and other flight or atmospheric conditions in the theatre of operation. The environmental effect is present in both the flight operations and in the aircraft maintenance environment at the deployed location. The environmental effects of the current operations in OIF and OEF are significant. The environment of operations includes some of the most austere conditions on earth. The temperature extremes in Iraq in the summer months are some of the most extreme on earth and in some instances are beyond the design standards and capability of much of the equipment employed. The sand

environment in Iraq and Afghanistan is austere and is a significant driver in maintenance actions and a significant causal factor to further aircraft damage.

7.0 FREQUENCY, SEVERITY AND TECHNOLOGY

The environmental causes to aircraft damage have changed significantly over the years of the operations and have been significantly improved due to technology insertions. The most direct impact of sand operations will be seen in the equipment breathing the air in that environment. Specifically that means engines and APU's requiring the air source to operate and the rotor systems that use the air supply to generate lift. All of these systems were significantly impacted and were a major maintenance and battle damage driver in the early operation of OIF. Unprotected blade systems were eroding in tens of flight hours. Engines power would degrade below minimum required power levels in tens of hours as opposed to hundreds of hours. Technologies to protect these systems were quickly introduced and have had a significant effect on mitigating the damage seen on aircraft systems. An array of filtration systems have been employed to protect air breathing engine and APU systems. Barrier filter systems are common on many systems that filter contaminants before entering the air path. Other systems utilizing centrifugal force separation of air and sand particles are employed on other systems.

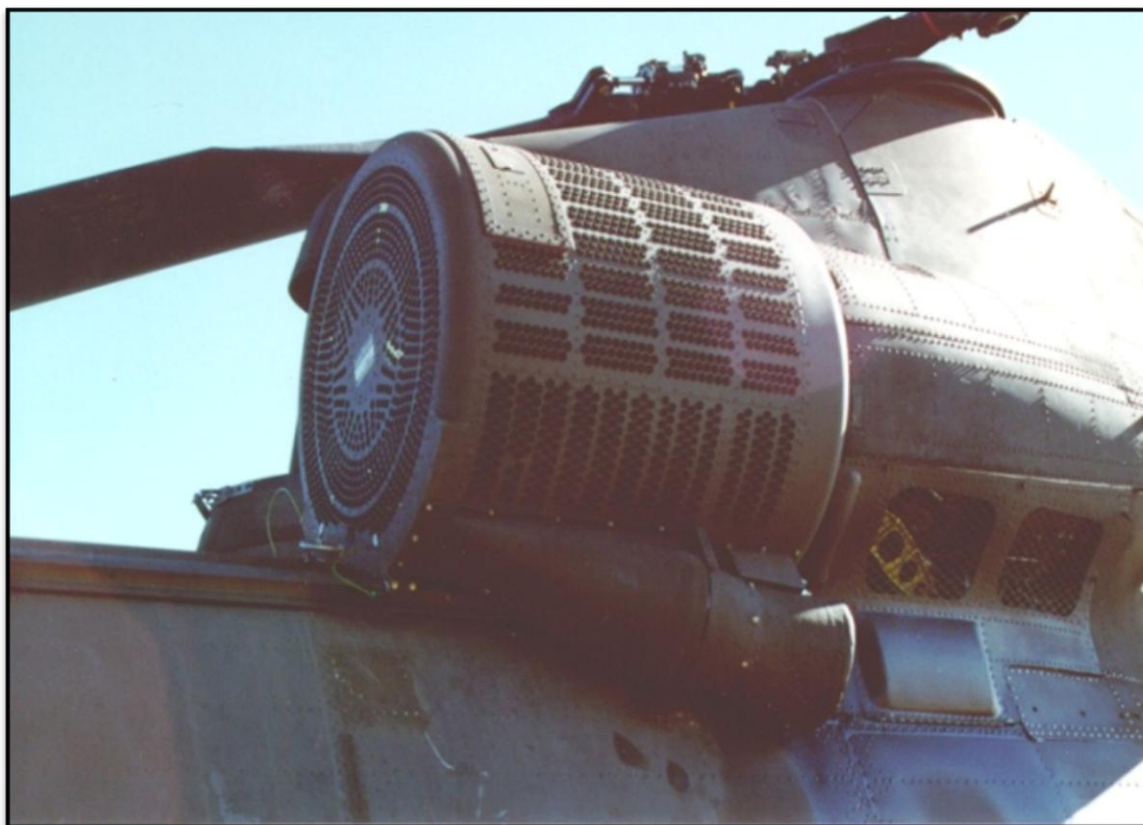


Figure 7: Engine Intake Barrier Filter (EIBF)

The rotor and blade systems of most aircraft now employ some form of blade erosion protection. In the early days of OIF this ranged from frequent painting to tape appliqué as a sacrificial erosion material. That technology has matured slowly with the advance in material solutions and the field application of those materials. The effects of sand environment on critical components have been significantly reduced due to the introduction and advancement of material solutions. An example of the advancement is the employment of HONTEC blade coated solutions in Iraq. The battalion worth of UH-60 blades were recently equipped on a rotation to Iraq. The blades lasted the entire rotation without a single blade failure due to erosion. The frequency of sand and dust environmental conditions is also mitigated based on the phase of the operations. The early stages of OIF operations were conducted from unimproved airfields and dust was a major problem. Current operations are predominantly from hardstand airfields and consequently, erosion problems are much reduced.

8.0 DEGRADED VISUAL ENVIRONMENTS

A special category of environmental conditions is Degraded Visual Environment. This is the broad category of any environmental conditions that result in reduction or elimination of pilot visual cues. The most prominent of these in OIF and OEF is “brownout” landing conditions. In the early period of the operations, brownout conditions were prevalent and caused many accidents or incidents. The number and severity of brownout incidents has been significantly reduced in recent years for several reasons. One reason is the TTP’s of the current operations has a much larger percentage of operations originating from hard stands. This alone minimizes the frequency of encountering of brownout conditions during operations. A second reason for brownout reductions is the introduction of aircraft with flight director functionality in the flight control systems. CH-47F and UH-60M aircraft have flight director modes that greatly enhance the ability to fly and land with little or no visual cues. There are also symbology solutions that have been sporadically fielded and add aided in the cockpit to help the pilot successfully land and takeoff in zero visibility conditions.

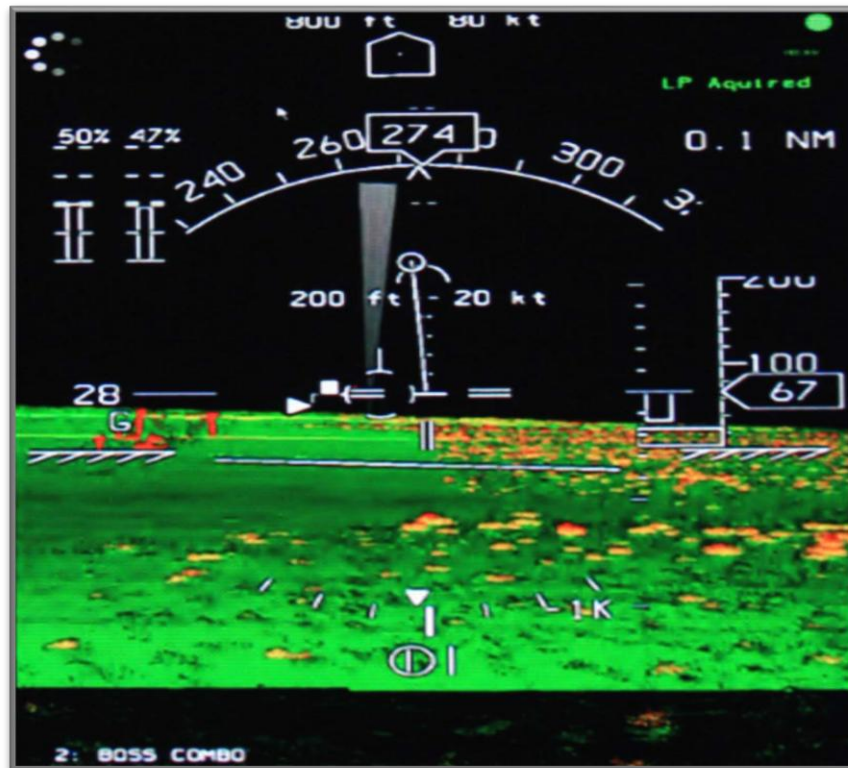


Figure 8: Symbology for Low Visual Cue Environments

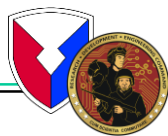
9.0 AIRCRAFT PERFORMANCE DEGRADERS

Many accidents and resulting battle damage to aircraft are a result of less than adequate aircraft performance and handling qualities. This is especially true in the low speed regime of flight. Helicopters with conventional rate command flight control systems are difficult to fly precisely especially in austere environmental conditions and under degraded visual conditions. Figure 10 shows the results of extensive handling qualities simulations and flight tests showing the handling qualities rating as a function Usable Visual Cueing. The data shows the only UCE condition where level 1 handling qualities are achieved for rate command control systems is in day conditions. This category of casual factor is closely coupled with the environmental factor since the issue is aircraft handling qualities in the presence of less than adequate cueing information. This category is separated out only because the potential solutions involve improving the aircraft as opposed to improving the visual cueing information. There is a lot of research that shows the beneficial effects of modern flight controls on rotorcraft. Figure 9 also shows the benefits to be gained by incorporating Attitude Command Attitude Hold (ACAH) and Translation Rate Command (TRC) control response systems. Figure 9 also briefly describes the different control response systems and their attributes, including a low speed flight control transition plot showing response due to a conventional rate command control laws versus response to modern ACAH and TRC command control laws in low speed flight.

10.0 FREQUENCY, SEVERITY AND TECHNOLOGY

Most aircraft incidents in this category are low speed events centered on landings. There are many hard landings reported with moderate to severe results. Some landings have ripped landing gear off aircraft. The

frequency of occurrence of those events remains high but is being reduced due the introduction of new aircraft models with better flight control systems, The CH-47F is in service and has on it a Digital Automated Flight Control System with the modern flight control laws. This provides for tremendous improvement in low speed and hover handling qualities and greatly improves this causal factor. The UH-60M also introduces a significant improvement in the outer loop flight controls with flight director functionalities of Hover hold and position hold autopilot features. This also has and will continue to reduce the frequency of this casual factor and is only limited by the rate of introduction of the aircraft model improvements.

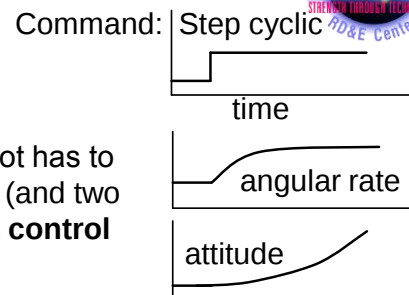


Flight Control Response Types



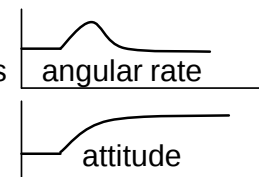
Rate Command (RC) means:

- Step pilot control input commands angular rate, so pilot has to integrate the response to predict the effect on attitude (and two more integrations for the effect on position) **a difficult control task even in good visual environment**



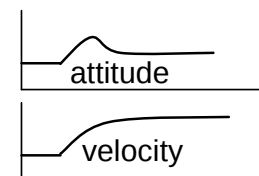
Attitude Command Attitude Hold (ACAH):

- Step pilot control input commands steady attitude change, centering the control returns the attitude change to zero and holds the attitude against disturbances.
- ACAH reduces pilot control task by one integration: **easier control task even in degraded visual environments**



Translational Rate Command (TRC) means:

- Step pilot control input commands velocity change, centering the control returns the velocity to zero.
- TRC reduces pilot control task by two integrations: **very easy control task (like driving a car)**



Technology to the Warfighter Quicker

Figure 9: Flight Control Response Types

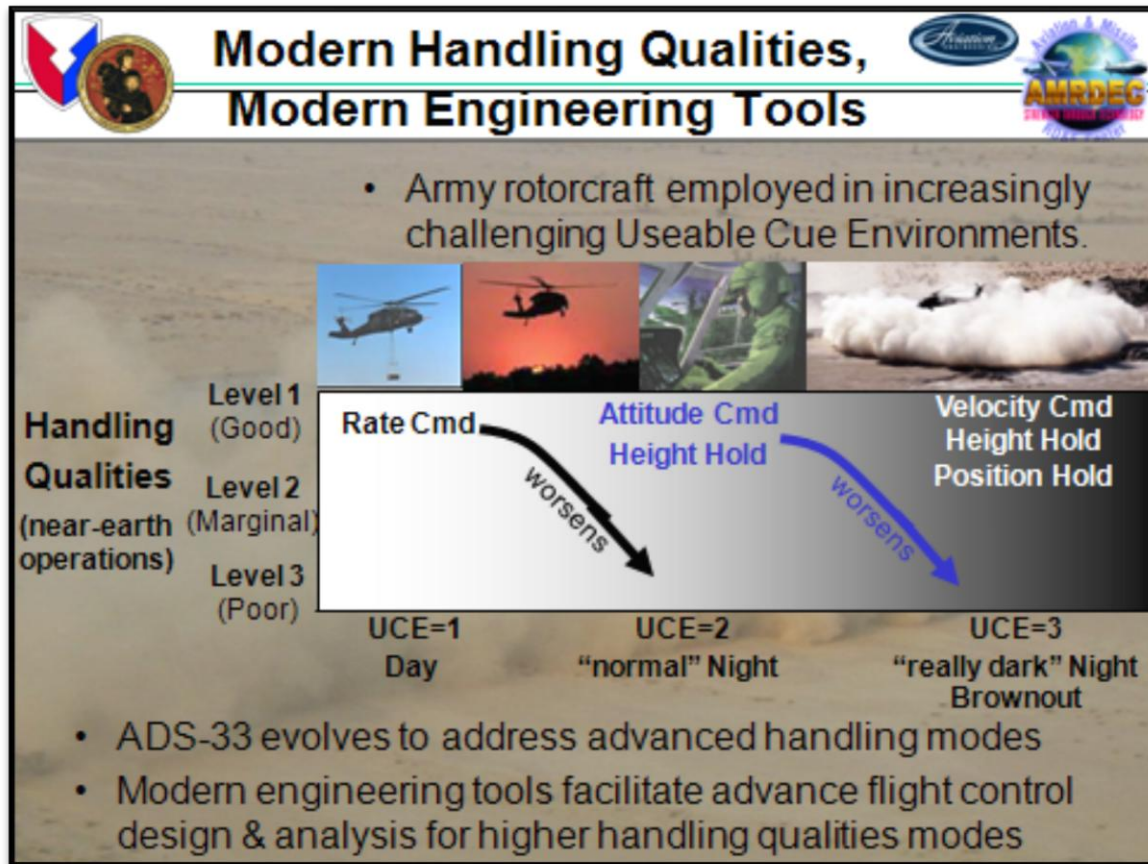


Figure 10: Modern Handling Qualities

11.0 CONTROLLED FLIGHT INTO TERRAIN (CFIT) AND OBSTACLES

CFIT is a classic aviation accident category representing powered flight into fixed terrain. For rotorcraft, this category is separate from the landing phase of flight. The factors here are situational awareness in the cockpit of the local terrain in the area of operations. The obstacle strike is a perpetual problem for rotorcraft with wires being the single biggest obstacle being struck. Wires are difficult as they are not necessarily a permanent terrain feature that would be included in data bases.

12.0 FREQUENCY, SEVERITY AND TECHNOLOGY

There are many technologies that have been fielded on modern helicopters that are significantly reducing the frequency of CFIT accidents. Those technologies center around incorporating a prior knowledge from terrain data bases into systems on the aircraft allowing for unprecedented Situational Awareness in the cockpit. Current DTED databases incorporated into moving map flight planning systems and displayed in the cockpit have helped reduce the CFIT accidents tremendously. The CFIT causal factor for the US Army has been significantly reduced almost to the point of being eliminated due to the situational awareness provided in the cockpit. Wire strikes on the other hand remain a significant problem. There are sensor technologies being worked to aid in seeing and warning crew in the cockpit of potential wires but these systems are immature, costly and heavy.

13.0 COMPARISON TO OSD STUDY

A recent Office of the Secretary of Defense study on aircraft survivability provides an excellent perspective to this topic of battle damage. The OSD study looked only at aircraft loss data from all services from the period of October 2001 to December 2008. The data examined included only class A data involving aircraft loss or fatalities. The results of the study parallel nicely with this topic and are discussed below

14.0 GOALS

The study looked at all accidents and categorized them into 3 loss categories:

- Combat Hostile Action,
- Combat Non-Hostile and
- Non-Combat.

Each of these loss categories has stated goals as outlined by congress. The goal of the Combat Hostile Action category was to have a loss rate less than or equal to that experienced in the Vietnam War. The goals for both the Combat Non-Hostile and the Non-Combat categories were to achieve less than 0.5 incidents per 100,000 flight hours.

15.0 OVERALL RESULTS

The study showed that the current rate of loss due to hostile action already showed a loss rate 6 times less that during Vietnam exceeding the congressional goal. The rate of loss of rotorcraft to Combat-Non Hostile exceeded the goal by a factor of 10 and the Non-Combat loss rate exceeded the goal by a factor of 4. These two areas are clearly the areas for improvement and technology focus. The overall results are shown plotted in graphic 1 below. It also shows the rotary wing aviation in relation to fixed wing aviation over the same time period. Clearly the rotary wing rates are higher than the fixed wing incident rates by approximately a factor of two. This is not surprising and is consistent with historical accident rates for fixed and rotary wing aircraft. The study also looked at causal factors for the incidents investigated and identified technology improvements necessary to achieve the stated goals of the congress and the OSD study. The causal factors are listed below in Chart x and are in general agreement with the causal factors presented in this paper for US Army experience. The technology improvements are also presented and are in agreement with the Army assessments presented in this paper.

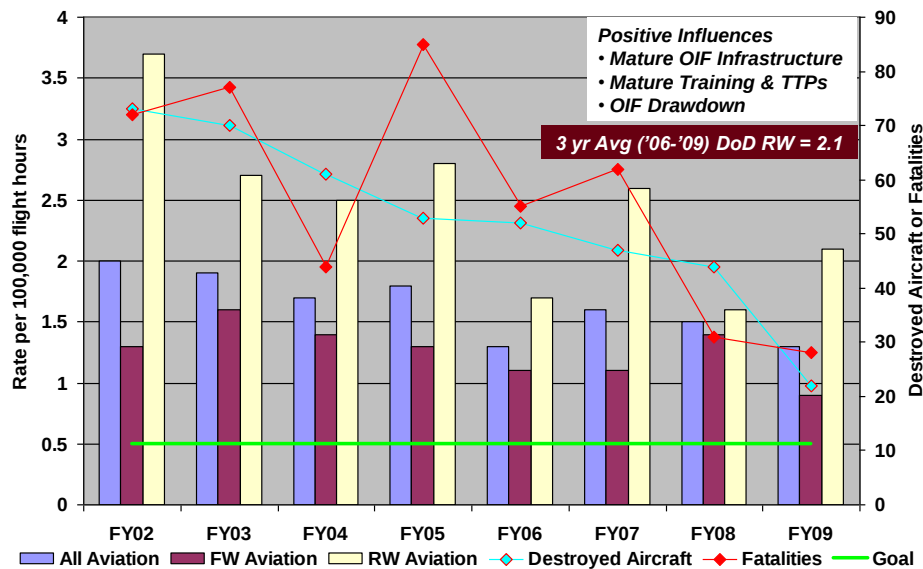
16.0 SUMMARY AND CONCLUSIONS

Battle damage has been assessed in terms of numbers of occurrence, rate of occurrence and causal factors. The effects of current operations in OIF and OEF have been discussed and the mitigating factors employed to date and potential new technologies have been discussed. The remaining sections of this lecture series will examine the processes and procedures of executing the aircraft battle damage assessments and repairs within the US army maintenance program.

Technologies Prioritization: The OSD study also looks at current and emerging technologies



DoD Aviation Class 'A' Mishaps (Combat Non-Hostile & Non-Combat as of 31 Aug 2009)



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Figure 11: DoD Aviation Class 'A' Mishaps



Top Priority Solutions for All Loss Causes (2010-2020)



Threat Weapons	Controlled Flight Into Terrain (cruise flight)	Improved Awareness: Terrain Warning (w/ digital database) Real-time weather updates combined with TAWS Low-power radar for obstacle detection	Improved crashworthiness and fire protection will not reduce the number of mishaps or combat losses, but they <u>may</u> reduce fatalities
	Degraded Visual Environment (low speed and hover)	Decreased Pilot Workload: Advanced Flight Control Systems Improved Awareness: Flight Displays w/ low Speed Flight Symbology Improved Facilities: Simulator & Training Area Realism & Availability	
	Guided Weapons (MANPADS, RF & IR Missiles)	Improved Awareness: Missile Warning Integrated Aircraft Survivability Equipment Improved Countermeasures: Improved Infrared Countermeasures & Infrared Expendables (New research, more capacity) Reduced Vulnerability: Fire Protection	
	Ballistic Projectiles (RPGs, Rockets & Small Arms/ Automatic Weapons)	Improved Awareness: Unguided Threat Detection Integrated Aircraft Survivability Equipment Improved Countermeasures: Optical Jamming/Dazzling Reduced Vulnerability: Fire Protection Ballistic Protection	

Addressing These Causes Would Significantly Reduce Rotorcraft Losses and Fatalities!

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Figure 12: Top Priority Solutions for All Loss Causes

